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(To be presented at the International Conference on Physics of High Energy Particles, Dubna, U.S.S.R., August 5 - 15, 1964.)

The recent experiments to which we here refer involve elastic $\pi^{\pm}$-p scattering between 300 and 700 MeV, charge-exchange scattering between 500 and 1300 MeV, and polarization measurements between 500 and 1000 MeV. The first of these[1] was accomplished at Saclay by a collaboration of Berkely and Saclay scientists, the second[2] is the current effort of cooperative research by Berkeley and University of Hawaii persons, and the third[3] is Berkeley work. We also report on the present status of the phase shift problem,[4] as studied independently by Roper and Cence.

I. ELASTIC SCATTERING, 300 to 700 MeV

The recent elastic scattering work was intended to provide information joining the low energy region up to 310 MeV with the region of the higher resonances, for both of which useful data already exist. Efforts at interpretation of the latter region have shown the importance of tracing phenomena continuously from the simpler regime at the lower energies. We are particularly concerned with an understanding of the "600 MeV resonance" (1512 MeV state) which bears a critical relationship to the symmetry schemes and pole trajectory analysis.

It is not possible in this paper to display the curves of differential cross sections for the fifteen different conditions of charge and energy at which measurements were secured. We shall state some qualitative deductions, and display plots of the coefficients of a cosine power series expansion of the T = 1/2 scattering, as a function of energy, as they are deduced from this work taken together with differential measurements of charge-exchange scattering.

In his amplitude analysis of the π^--p scattering results, Ogden made the plausible assumption of the existence of the following resonance conditions:

State	$E^{c.m.}_{res.}$	$x = \frac{\Gamma_{el}}{\Gamma}$	Γ
P_{33}	1238 MeV	1.0	165 MeV
D_{13}	1512	0.8	110
F_{15}	1688	0.9	100

With this assumption it was then found the data could be satisfied by the following additional amplitudes:

1. A pure-imaginary $S_{1/2}$ amplitude, taken to be constant at 0.27 $\bar{\lambda}$, over the 300 to 700 MeV region.
2. A pure-imaginary $P_{1/2}$ amplitude, similarly constant at 0.35 $\bar{\lambda}$.
3. A D_{15} amplitude which begins slowly to appear at 400 MeV, and which rises rapidly after 600 MeV. (The strong $D_{15}F_{15}$ interference at energies increasing toward 900 MeV is of course well established by previous work.)

This qualitative description of amplitudes through the region of the 1512 MeV state is not unique, as we shall observe subsequently in discussing phase shifts.

It is instructive to combine the data of this experiment with that from the Berkeley-Hawaii charge exchange experiment, and from recent measurements by Lind et al.[5] at 315 and 370 MeV, in such a way as to extract the pure T = 1/2 elastic scattering. The coefficients of the cosine power series expansion, as functions of energy, are displayed in Fig. 1. Scattering data from the well-known work of Helland et al., were also employed in this treatment.

As we should expect, the evidences of the $D_{15}F_{15}$ interference near 900 MeV stand out even more strongly than in π^-p curves. An interesting feature of the a_o curve is its single peak at about 450 MeV; this is conceivably related to a J = 1/2 enhancement such as that reported by Bareyre et al.,[6] since both S_{11}^2 and P_{11}^2 terms will contribute to a_o. The absence of a peak at 600 MeV from the D_{13}^2 contribution is explainable by reference to the $S_{11}D_{13}$ interference term which will subtract from D_{13}^2 if the S_{11} amplitude is near the D_{13} in phase.*

In view of the phenomenally sharp rise of S-wave η^o production to a maximum at about 600 MeV, as observed in our work reported in this conference by V. Z. Peterson, we infer that an S_{11} amplitude of the required strength is conceivably available to accomplish this interference.

II. CHARGE-EXCHANGE SCATTERING

At present we can report upon the basis of analysis of part of the experimental data secured. Angular distributions for two of the seven energies are displayed as examples in Fig. 2; and in Fig. 3 we show the energy-dependence of the coefficients in the cosine power series expansion. The intercepts at $\cos\theta = 1$ for our $d\sigma/d\Omega$ curves are in fairly good agreement with the results of the forward-direction experiment of the Saclay group,[7] although the absolute-precision of our experiment is not as high at 0-deg and 180-deg as in directions removed from the beam line. The total and partial cross sections for the reactions yielding neutral final states, including η^o production, as observed in this experiment have been presented by V. Z. Peterson in this conference.

The first conclusion which was drawn from the data was that the FD interference observed strongly in the region of 900 MeV in π^--p scattering arises from T = 1/2 amplitudes only. This is immediately clear from the T = 1/2 differential cross sections extracted from the combination of charge-exchange and elastic scattering.

The further function of the data is to provide important constraints in

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*We should note also that this same S_{11} D_{13} contributes strongly in a positive sense in a_2 to provide the abrupt rise between 500 and 600 MeV.

the phase shift analysis attempts. We have not attempted to infer information about ρ-meson exchange from our forward-direction angular distributions until we are confident that details of their shapes are as well-determined as our data will allow.

III. POLARIZATION MEASUREMENTS

The angular dependence of recoil proton polarization in $\pi^{\pm}$-p elastic scattering has been obtained at pion energies of 523, 572, 689, 864, 981, and 1301 MeV. The statistical strength of the data is unfortunately too low to allow detailed interpretation, but the following comments can be made:

1. P(90 deg) in π^-p scattering is negative below 700 MeV, and again becomes strongly negative about 900 MeV. (At 981 MeV, P(90 deg) = - 0.84±0.16). Since this is due to superposition of states of opposite parity, it is not unexpected in these regions; but it is surprising that P(90 deg) should be positive at 689 MeV.

2. In π^+p scattering P(90 deg) is negative below 700 MeV, presumably due to SP interference, and remains positive at the energies measured above 700 MeV.

The data at all angles are employed in the phase shift search problem. Values of the coefficients, b_n in the expansion:

$$P(\theta)\sigma(\theta) = \sin\theta \sum_n b_n \cos^n\theta,$$

are given in the following table. The values are in millibarns.

	$10^{-2}\,b_0$		$10^{-2}\,b_1$		$10^{-2}\,b_2$	
T_π	π^+	π^-	π^+	π^-	π^+	π^-
523	-14±4	-25±6	-57±19	-146±30	-62±22	-157±42
572	- 5±3	-16±4	-38±14	-149±26	-43±18	-277±41
689	- 2±2	5±3	-41±12	- 75±22	-24±21	-207±43
864	3±2	- 8±3	10±10	5±10	77±20	60±35
981	0±3	-26±2	-25±13	32±9	39±29	93±27

Because of the poor statistics and incomplete angular coverage it was not useful to use orders greater than two in the series.

IV. PHASE SHIFT CALCULATIONS

R. J. Cence of the University of Hawaii and L. D. Roper of the Lawrence Radiation Laboratory (Livermore) have independently dealth with the phase shift problem using different procedures. Roper has parameterized the phase shifts as functions of the c.m. pion momentum by a power series expression, and has then sought to simultaneously fit all data at all energies. Cence has not imposed such constraints, but rather seeks to find separate solutions at successively higher energies by employing at each new energy an input array of phase shifts obtained at the last preceding energy. He thus develops a sequence of sets which should show the energy dependence of the phases without limiting their freedom to vary as nature may require. Both men utilize all existing types of data on cross sections and polarization.

The present results set forth by Roper for the vicinity of 600 MeV show a P_{11} resonance at 570 MeV and a D_{13} resonance at 650 MeV. Both are strongly inelastic. He had assumed in his input data a Breit-Wigner D_{13} resonance form. The chi-square value of his fit to the total array of data in 2910, where he has employed approximately 1200 separate datum points and has admitted partial waves through $\ell = 4$.

The double resonance spanning 600 MeV seems unique to Roper's analysis. Actually these are both so strongly inelastic in his results that the behavior of the real parts of the P_{11} and D_{13} phases is not crucial. While it is appealing to attempt to fit all data simultaneously, the question may be raised as to whether the constraints imposed by the parameterizing of the energy dependence may not enforce an unwarranted smoothness and other apparent phenomena. His predictions of physical results which have been subsequently measured have been very satisfactory however.

The sequence of phase shift sets for various energies as generated by Cence are also excellent fits to the data. Cence has used some additional inelastic cross section data not available at the time of Roper's analysis. He began with the Vik-Rugge II solutions for 310 MeV, and imposed no assumed resonances except the P_{33} existing at 200 MeV.

None of Cence's phases pass through resonance behavior, although certain phase excursions produce the amplitude variations required by the data. The chi-square values of his fits at the various energies between 310 and 873 MeV lie between 30 and 100, and the numbers of datum points employed at the various energies range from 50 to 80. He includes partial waves through $\ell = 3$ only. The manner in which his S_{11}, P_{11}, P_{13}, and D_{13} phases vary as the energy increases allows certain plausible speculations associated with thresholds and final state interactions which cannot be pursued within this space.

We present in the following table the set derived by Cence for 600 MeV. It is far more instructive to see the sequential values of the phases as the energy advances, but the array of data is of prohibitive extent.

	S_1	P_{11}	P_{13}	D_{13}	D_{15}	F_{15}	F_{17}
δ_{real} (deg)	28.3	44.6	-32.4	29.7	-4.2	5.1	-0.9
$\eta = e^{-2\delta_{imag.}}$	0.86	0.75	0.66	0.96	0.93	0.91	0.89

	S_3	P_{31}	P_{33}	D_{33}	D_{35}	F_{35}	F_{37}
δ	-28.2	-12.1	-17.9	3.5	-4.8	-0.1	2.6
η	0.87	0.89	0.92	0.98	0.98	0.99	0.96

In the T = 3/2 state the results of Cence and Roper are in rough agreement, as is also true for S_{11}. They both started from the same values at 310 MeV.

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* This work was supported by the U. S. Atomic Energy Commission.

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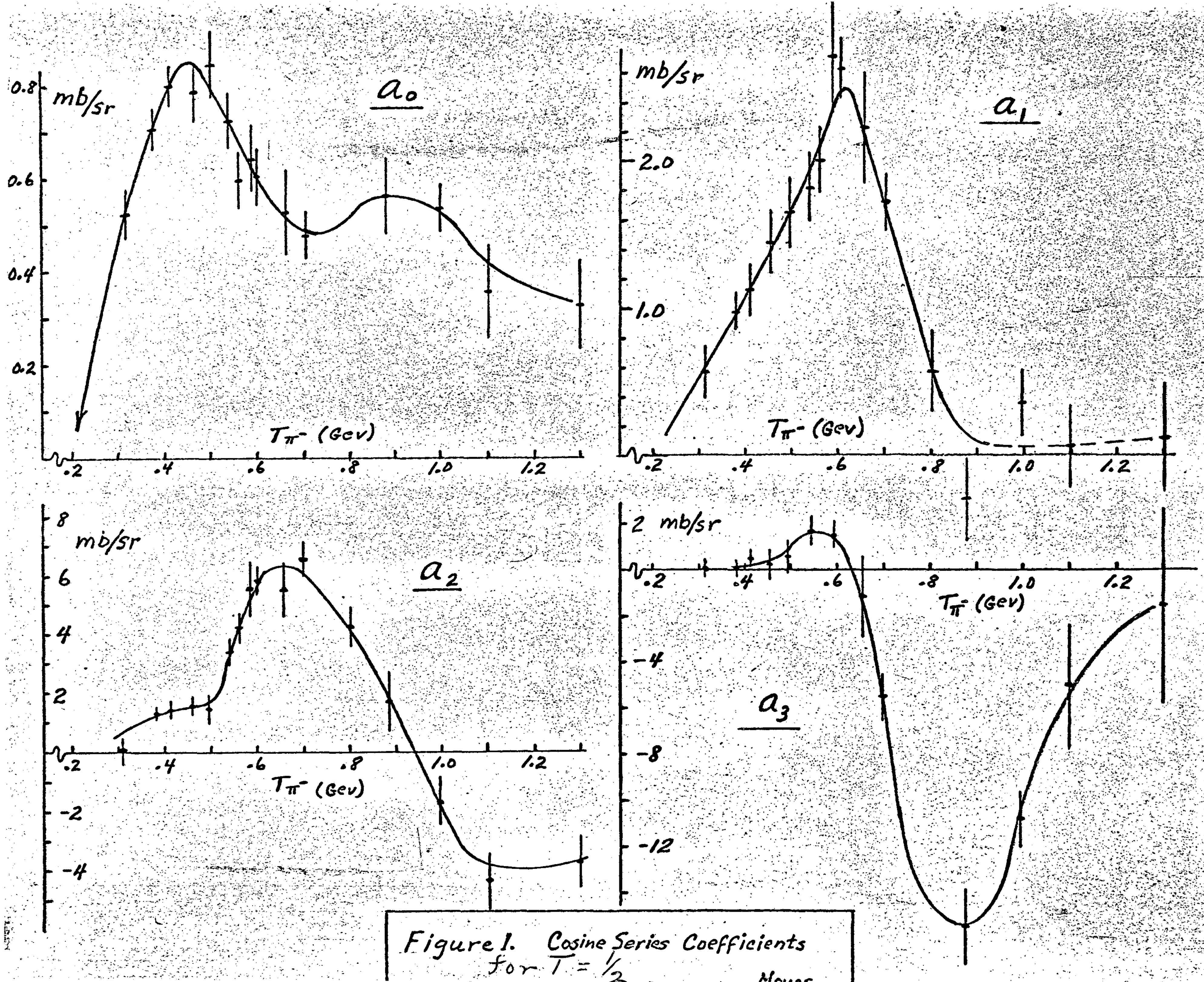

Figure 1. Cosine Series Coefficients for $T = \frac{1}{2}$

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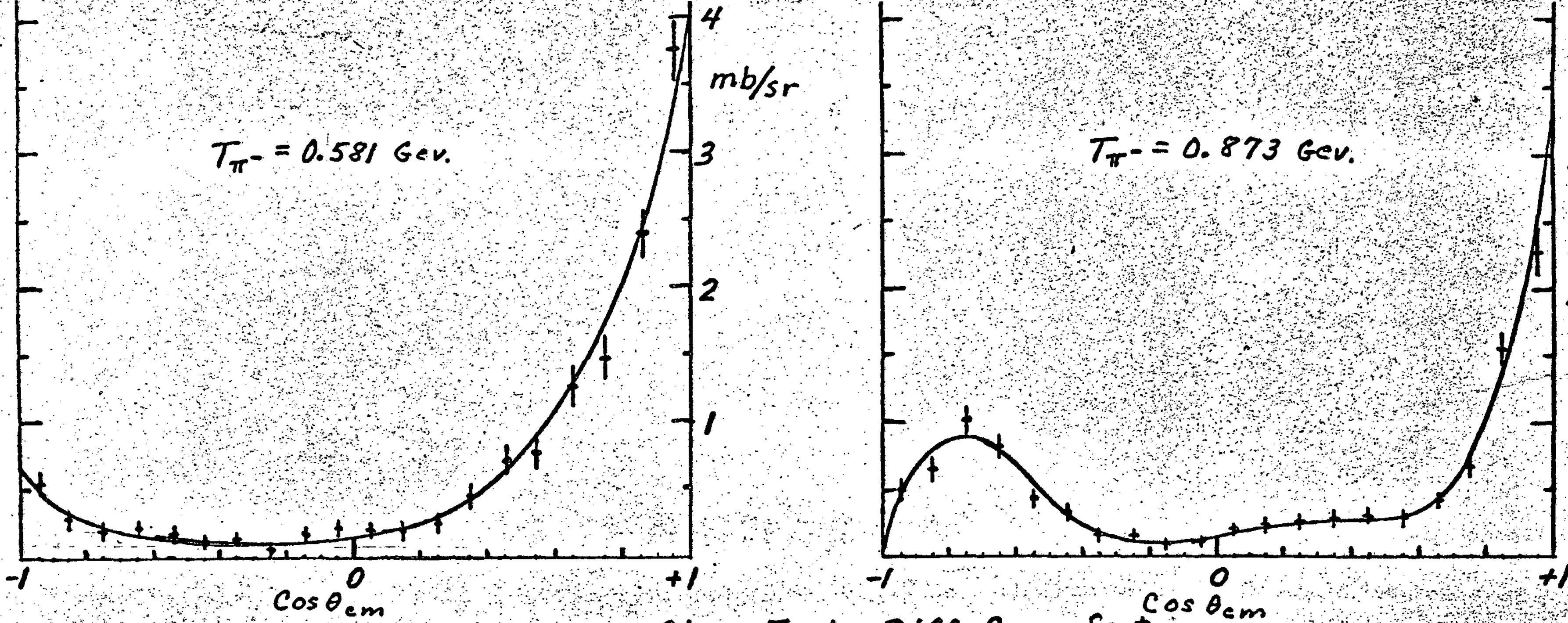

Figure 2. Chg.-Exch. Diff. Cross Sect.

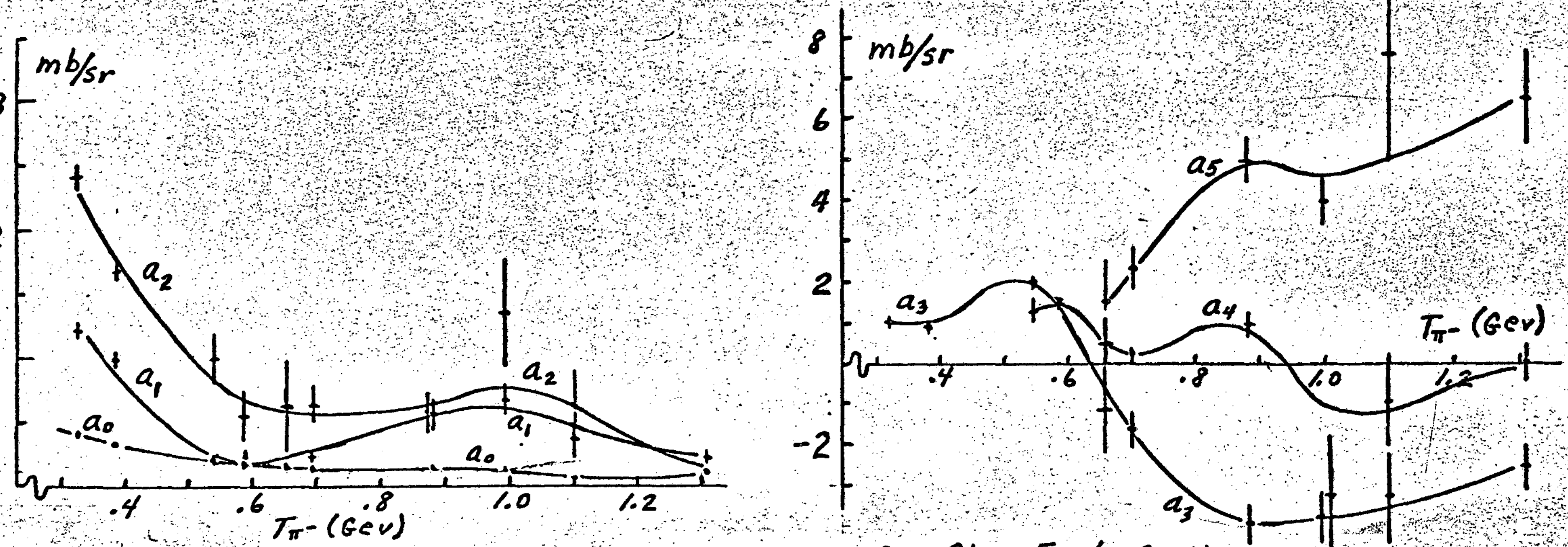

Figure 3. Cosine Series Coeffs. for Chg.-Exch. Scatt.